

# Exploring dynamic lighting, colour and form with smart textiles

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**Abstract.** This paper addresses an ongoing research, aiming at the development of smart textiles that transform the incident light that passes through them – light transmittance – to design dynamic light without acting upon the light source. A colour and shape change prototype was developed with the objective of studying textile changes in time; to explore temperature as a dynamic variable through electrical activation of the smart materials and conductive threads integrated in the textile substrate; and to analyse the relation between textile chromic and morphologic behaviour in interaction with light. Based on the experiments conducted, results have highlighted some considerations of the dynamic parameters involved in the behaviour of thermo-responsive textiles and demonstrated design possibilities to create interactive lighting scenarios.

## 1. Introduction

The emergence of smart textiles presents the potential to enhance and involve physical and immaterial dimensions, promoting added functionality and interaction between individuals and their environment. Within an interdisciplinary context, the development of reactive and adaptive textile systems requires knowledge and competences in diverse domains that entail new perspectives and challenges for design practice [1, 2].

This paper addresses an ongoing research, aiming at the development of smart textiles that transform the incident light that passes through them – light transmittance [3] – to design dynamic light without acting upon the light source. Interaction of textiles and light were explored through colour and shape change behaviour.

Thermochromic (TC) leuco dyes are a class of colour change materials that through a thermal stimulus change their optical characteristics reversibly [4]. As dark colours absorb a greater intensity of the visible light spectrum than lighter colours [3], TC textiles affect the light that passes through them, when they are below or above their activation temperature.

Furthermore, different amounts of textile layers also interfere in light transmittance, depending on the light absorbed. With shape memory materials, defined by their ability to change from a temporary to a memorized shape [5], it is possible to develop textiles that perform morphological variations with variable number of layers. Nitinol was the shape memory alloy selected.

A previous materials' research was conducted with the objective of developing processes to integrate the selected smart materials in textile substrates. The results attained have outlined two

process proposals to elaborate paste recipes of TC and conventional pigments in order to screen-print textiles with defined colour ratios: from similar to different colours with the temperature increase and the inverse [6, 7]; and a workflow setup to design and manufacture woven substrates that perform shape change based on predefined geometric morphologies [8, 9]. Additionally, conductive materials were studied to activate the two thermo-responsive materials through resistive heating.

Aiming to explore colour and shape dynamic behaviour in interaction with light, this paper discusses a design research conducted by implementing the results previously attained and exploring dynamic variables through a smart textile prototype.

## 2. Research prototype dynamic behaviour

*Narratives of Winter Daylight* is a research prototype inspired by the dynamic qualities of natural light. Day and night commonly present different rates and changing patterns of light intensities, colours tones and direction, depending on the geographic location, season and weather conditions. For this study, one winter daylight was observed and photos were recorded each hour from 6 a.m. to 6 p.m. Figure 1 presents the photo record conducted on 31.12.2015 in latitude: 41.178084, longitude: -8.66061, with equal camera settings for a comparison between luminosities.



Figure 1. Photos record from 6 a.m. to 6 p.m.

Patterns and expressions of light change were analysed with perceived luminosities and tones, which set up a basis to define the prototype colour change palette and shape changing geometries in order to study the textile behaviour in interaction with light.

The prototype morphology presents two pill up textile layers. The front layer combines six folded units aligned horizontally and each unit consists of a mirrored sequence of two vertical pleat folds. Attached to a plain textile layer (back layer), the folded geometry creates areas with a variation of textile layer number and distance, through the fold up and fold down movements of the pleats.

Width proportion and colour change of each pleat unit was defined in regards to the luminosity and colour similarities during the time period of the winter daylight observed. With increasing temperature, the prototype changes from a dark blue colour to different colours.

Designing with temporal forms – colour and shape as textile temporal forms – extrapolates the definition of the physical medium to embrace the dynamic variables of the textile behaviour, as they play crucial roles in the expressions and/or functionality of the design outcomes [2, 10].

Perception of natural light variations involve a relation between the luminosities observed with established expectations and rates of change [11]. Commonly, subtle light changes are expected during the day, while more obvious changes are prevalent in early morning and late afternoon. Rhythms of light variation can allow an experience of the passing of time, perceived not only by the changes of the light parameters that vary but also in respect to the duration of the events in time [12].

In this research, the duration of changes depend on the heat stimulus that activates the textile colour and shape variation and cooling conditions, as the materials applied present gradual transformations during a temperature interval. Thus, temperature was studied as a dynamic design variable to explore possibilities in colour, form and light performances.

### **3. Materials and Methods**

The smart materials handled in this research were: body temperature Nitinol alloy (Austenite start 30°C and Austenite finish 45°C) with 0,3 mm diameter and TC pigments of 27°C activation temperature in magenta, blue and black colours.

#### *3.1. Textile prototype development*

Defined to change from similar to different colours and to vary the textile layer number and distance, the textile prototype development has involved:

a) Definition of textile shapes and respective weaving plan for Nitinol wires integration; definition of Nitinol geometries encompassing two sets of Nitinol wires (one group to perform fold up and another for fold down); drawing and production of dies; optimization of the annealing parameters followed by Nitinol heat treatment; and sandblasting of Nitinol wires' ends [8].

b) Weaving of the textile substrate in a plain weave structure with cotton yarns in the warp and polyester yarns in the weft, where conductive threads were woven at every 1,0 cm and the Nitinol alloys were integrated at every 2,0 cm, with 0,5 cm distance of the conductive threads.

c) Formulation of screen-printing paste recipes given a pattern colour, through a database created with colourimetric properties of the TC and conventional pigments handled [6]; elaboration of the pastes; screen-printing of the textile substrate; and thermo-fixing.

d) Connection of the conductive materials with four circuits for each pleat unit – two series circuits of connected conductive threads, one for colour change in the front layer and another for the back, and two series circuits of Nitinol segments linked according to fold up and fold down groups;

e) Application of an electrical insulating agent; folding of the prototype and setting up in a light box, built with two strips of warm white LEDS (2700K) in the box inner top and bottom;

f) Definition and manufacturing of the electrical circuit; activation sequences plan and programming.

#### *3.2. Study of textile and light behaviour*

Light transmittance variation and textile behaviour were studied, in regards to the prototype chromic and morphologic definitions as well as changes attained with temperature increase through resistive heating and decrease by interruption of power supplied. All experiments were conducted at an ambient temperature below the smart materials' activation temperatures.

The electrical current required to attain the temperature increase of the conductive threads for colour change and Nitinol activation for shape change was studied through voltage variation applied with a variable power supply. Duration and expression of changes were analysed for each circuit and by simultaneous or sequential activation of circuits. An infrared camera was used to measure the temperature attained and to avoid overheating.

### **4. Results and discussion**

Figure 2 presents the prototype in fold down and fold up activation states, the front view in the two images on the left and one pleat unit in perspective in the right images. Differences of light transmittance are observed through the overall change of luminosity, in the textile and by the light falling on the wall.

With the fold down activation, textile layers are near and light transmittance is low in comparison to the morphologies attained with fold up activation, where the pleats unfold and create 'open pockets' that increase light transmittance. Pleat units with larger width (1st and 4th pleat units in images on the left) attain a larger distance between layers, achieving higher luminosity variation than units with lower widths.

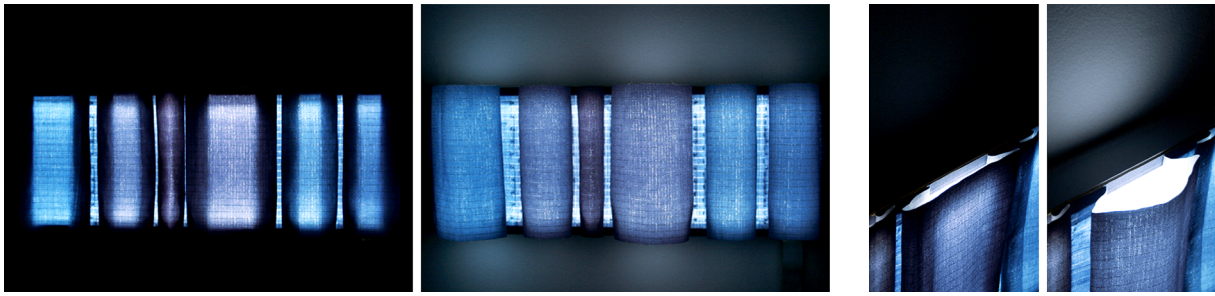


Figure 2. Prototype fold down and fold up activation.

Fold up and fold down behaviour were tested with an electrical current variation from 0,6 to 0,9 A, to analyse the time required to heat up the Nitinol alloys above their activation temperature and consequently change shape. Tests were conducted at an ambient temperature of approximately 20°C and mean values attained for each circuit were 14 seconds with 0,6 A, 10 seconds with 0,7 A, 7 seconds with 0,8 A and 5 seconds with 0,9 A. Movements performed appeared organic and subtle.

Through the shape change analysis conducted during activation, it was observed that folded states attained lower angles than the memorized geometries of the Nitinol alloys. Textile substrate and morphology have constrained the Shape Memory Effect (SME), in particular with the lower width pleat, where movements were barely perceived although the Nitinol wires were above their activation temperature, as confirmed with a thermal camera.

Furthermore, if fold down is activated immediately after the fold up, or the inverse, Nitinol alloys are in the process of recovering the pre-memorized shape, when the other Nitinol group is still above the temperature that can be deformed. There is a time duration increase to attain the complete shape change, in regards to the time required for the actuator group previously heated up to cool below 30°C. If the power supply encompasses a pause in between fold up and fold down activations, a slight shape change can be observed when the actuator group previously heated up, cools down.

Time for the Nitinol alloys to cool down depends on the temperature previously attained with the electrical current supplied, ambient temperature and textile substrate characteristics. Furthermore, thermal images have also demonstrated that wire temperature is not homogeneous. Therefore, the definition of time to cool down the Nitinol below its activation temperature requires experimentation. With the prototype circuits and ambient temperature of 20°C, values varied between 5 and 20 seconds.

Prototype colours change from similar dark blues to different colours with temperature increase: dark blue tone, grey, white, light blue, blue and violet dark blue, from left to right (figure 3).

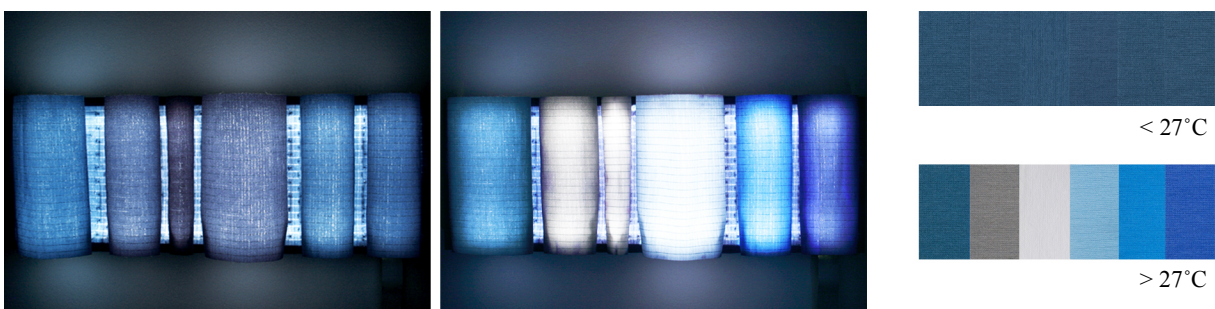


Figure 3. Prototype fold up without and with colour activation (left and middle); and colour samples in natural light, below and above 27°C (left).

Colour tones perceived by direct observation and with the textile placed in a light box have differed. Colour measurements conducted below 27°C in a reflectance spectrophotometer have confirmed colour similarities. CIELAB differences attained values between 0,8 to 1,3 dE\*, which can be considered reasonable for colour matching. In the light box, samples screen-printed with pastes that combined TC pigment blue (2<sup>nd</sup>, 3<sup>rd</sup> and 4<sup>th</sup> pleat units in figure 3 left) instead of conventional

pigment blue, presented a violet nuance. Paste recipe adjustments were conducted, although a subtle violet tone remained.

Light transmittance variation with the colour change effect, created a hierarchy of luminosity differences, as targeted: an increase from the first to the third pleat (6 to 12 a.m.); similarities in third and fourth pleat (12 to 2 p.m.); followed a decrease until the sixth pleat (3 to 6 p.m.). Light measurements with one layer of each colour sample confirmed the observations, percentual luminosity differences varied from 13% to 76, 93, 88, 58 and 30%, in respect to the above-mentioned sequence.

Colour change activation was produced through the flow of electrical current on the conductive threads integrated in the woven substrate at every 1,0 cm and thermal expansion in the textile areas in between. Time required to attain full colour change and full colour return were tested at an ambient temperature of 20°C, with an electrical current variation from 1,0 to 1,4 A. Figure 4 presents the fourth pleat in a sequence of colour change activation from the first to the third image and on cooling from the third to the sixth image. During heating, colour changes from a striped pattern to a complete area. On cooling, nuances of colour return display less visual relevance of the conductive thread lines. Table 1 presents the mean values attained during electrical current supply in the front layer of the fourth pleat unit, for duration of change and maximum temperatures, measured with an infrared camera.

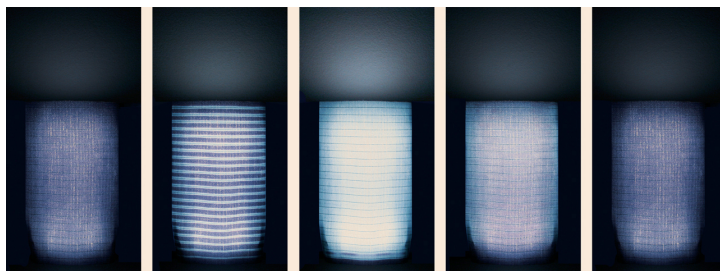


Figure 4. Colour change activation from 1<sup>st</sup> to 3<sup>rd</sup> image and on cooling from 3<sup>rd</sup> to 6<sup>th</sup> image.

I (A)	heating		cooling	
	time	max. temp. (°C)	time	max. temp. (°C)
1,0	(5')	36,8	50"	25,2
1,2	2' 30"	43,3	1"	25,9
1,4	1' 40"	50,9	1' 20"	25,0

Table 1. Mean values of colour change duration and maximum temperatures.

Full colour change was not attained with 1,0 A, the temperature on the conductive threads changed the textile colour but was not sufficient to completely heat up the textile areas in between them. With 1,2 and 1,4 A, full colour change was observed with higher time duration on heating with 1,2 A and the reverse on cooling. To study the possibility to maintain the textile in full colour change, an additional test was conducted with electrical current of 1,2 A, supplied during 5 minutes. Maximum temperature on the conductive threads was 41,9°C after 1', 43,0°C after 2'30'' and 45,1°C after 5', acknowledging the possibility to perform colour change for the time defined, without overheating.

During the tests conducted, it was also observed that duration of colour change was faster when both front and back layers were activated at the same time. The temperature inside the folded layers increased, enhancing the textile thermal expansion and, due to the vertical positioning of the prototype, the upper area of the pleat units also heated up faster than in the bottom.

Ambient temperature significantly affects the duration of change and the ability to perform full colour change. Tests repeated with 1,2 A at an ambient temperature of 17°C, did not attain full colour change and with 1,4 A required 4 minutes on heating and 1 minute on cooling.

Combination of shape and colour activation was also analysed. In the prototype developed, it was defined that Nitinol activation does not change colour, and the screen-printing paste applied for the alloys areas only combine conventional pigments. During colour change, the temperature increase in between the textile layers can induce changes in fold down and fold up groups, assuming a morphology between states. Electrical activation of colour and shape change, can create different variations of light transmittance intensity and expression. For example, total colour change in a fold down state is observed almost exclusively through the textile light transmittance, while when folds up, light transmittance increases and is more obviously perceived with light falling on the wall. Within

different possibilities of activation sequences, rhythms of continuous change of light transmittance can be created. Based on the variation paces of daylight observed, mostly slow and subtle and less evident changes, textile and light sequences were defined and programed, through an electrical circuit controlled by a microcontroller board.

The prototype was presented in a spatial context where spectators also took an active part on the interaction, since they were the ones who triggered the sequence selection and activation, depending on its location in the space. The sensors used detected the presence of spectators, communicated via wireless with the microcontroller and activated visual sequences of *Narratives of Winter Daylight*.

## 5. Conclusions

This study implements the results attained in a previous materials' research and explores dynamic colour and form with a smart textile prototype in interaction with light. Experiments conducted through electrical activation of the textile behaviour have highlighted the importance of temperature and time of activation in the performance and expression of changes, illustrating some considerations that can be applied when working with thermo-responsive textiles.

Light transmittance variation created through rhythms in the textile colours and shapes, can be defined with sequential and/or simultaneous activations during time. Activation of different configurations enable the creation of interactive lighting scenarios, where dynamic qualities can be perceived as obvious or subtle, according to how textile behaviour and light are designed.

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